N65-29458
(ACCESSION NUMBER) (THRU)
65 1
(PAGES) (CODE)
TMX-51903 30
(NASA CR OR TMX OR AD NUMBER) (CATEGORY)
FACILITY FORM 602

HIGHLIGHTS OF RECENT SPACE RESEARCH

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GPO PRICE $ ________

CFSTI PRICE(S) $ ________

Hard copy (HC) 3.00

Microfiche (MF) .75

ff 653 July 65

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29458

Space science is the collection of scientific problems to which space vehicles can make some specific contributions not achievable by ground-based experiments. At the present time this field includes broad segments of the traditional disciplines of the earth sciences, physics, and astronomy. In later years the biological sciences will join this group in an important role, as our explorations of the moon and planets provide us with opportunities for studying the conditions under which physical life may have developed. The present article reviews some highlights of recent space research in the physical sciences.

Author

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GEODESY

Important results have been achieved in determining the internal structure of our own planet with the aid of near-earth satellites. A satellite's orbit is determined by the distribution of mass within the earth. If the earth were a perfect sphere, under the attraction of the mass point at the earth's center of gravity the satellite would move in an ellipse whose plane would keep a constant orientation in space.

Actually, the plane of a satellite's orbit rotates slowly in space, due to the additional force of attraction exerted by the equatorial bulge. Studies of the orbital rotation rates of a number of satellites have yielded a very precise value for the height of the equatorial bulge. These indicate a discrepancy between the observed value of the flattening and the value that should exist on the assumption of hydrostatic equilibrium. It has been suggested by Munk and MacDonald that these results imply that the interior of the earth is not in hydrostatic equilibrium but has a mechanical strength within its interior sufficient to maintain its shape in spite of the stresses at the base of the mantle.

There are other departures of the geoid from the shape of hydrostatic equilibrium, in addition to the discrepancy in the flattening. These departures are of very great significance because they represent variations in gravity which depend on the entire distribution of mass within the planet, which are more significant for the gross structure of the planet than the simple topographical variations, e.g. mountains, which represents only the distribution of the mass at the surface alone.

Detailed analysis of these gravitational variations yields a figure of the earth in which there is a positive anomaly, or a lump, in the region of the western Pacific, near Indonesia and the Philippines, a large depression or negative anomaly in the Indian Ocean, and a negative anomaly, in the Antartic. (Figure 1)

Although these depressions and elevations are relatively minute, they are exceedingly significant because they represent variations in the force of gravity, or the amount of matter/cm^2, in the regions in question. For example, the depression in the Indian Ocean is only 60 meters deep, but it signifies that the force of gravity there is, relatively, so weak that the waters of the sea are not drawn together to the depth that one would expect for them if the whole earth were subject to a uniform gravitational force.

These anomalies are correlated with the rate at which heat flows through the body of the earth to the surface. The correlation is such that where the geoid is anomalously high, the heat flow is anomalously low. On the average, the flow of heat outward through the crust of the earth is 60 ergs/cm^2 sec. In the depression of the geoid near India, the flow of heat is substantially higher, 80 ergs/cm^2 sec. At the elevation of the geoid in the western Pacific, the flow of heat is substantially lower, about 40 ergs/cm^2 sec.

We expect this kind of correlation if there is a mass transport, or convection of matter, from the deep interior of the earth to the surface in these regions. If there were an upward motion through the interior of the earth which carried relatively warm material from below to the surface, this upward-moving column would have a lower density than its surroundings, and therefore the mass per cm^2 in the column and the gravitational force on the surface of the earth about it would be lower than on the average. At the same time, the heat which the warm column transports upward would add to the normal release of radioactive heat throughout the mantle and crust, so that above the same upward-moving column there would be an exceptionally large rate of heat flow through the surface. The converse would hold for a descending column, which would carry a relatively dense and therefore relatively cold material from the surface layer to the interior of the earth. Above the cold and dense column the gravitational force would be relatively great, and a bump would appear in the sea level there. This may be the cause of the elevation in the western Pacific.

METEOROLOGY

In geocentric order, the next major area of investigation in space science concerns the atmosphere and the control exerted over it by the sun. This field of research includes questions related to the circulation of the winds in the lower atmosphere and to the vertical structure of the atmosphere at higher altitudes.

Regarding atmospheric circulation, eight TIROS satellites have been launched in the past four years, all carrying vidicon cameras for the global study of the cloud cover; TIROS II, III, IV, and VII carried in addition a set of infrared detectors for the measurement of the intensity of infrared radiation emitted from the earth-atmosphere system.

The cloud cover photographs have already yielded results of great interest when correlated with ground observations, and they have the promise of leading to a substantial improvement in weather forecasting by providing global and nearly continuous coverage of regions of weather activity. The matter of global coverage is critically improvement, because the success of weather forecasting has been found to increase rapidly with the size of the region covered by the observations; yet at the present time large parts of the globe are very poorly covered.

They constitute regions in which weather activity can develop and grow without detection before moving out into the inhabited areas. The sparsely covered territories include the polar regions, the major deserts, and the southern oceans. Satellite coverage will greatly strengthen the hand of the meteorologist by filling in these blank portions of the global weather map and may be expected to have important consequences for the economies of this country and the world.

The cloud photographs can also be important for the basic objectives of long-range forecasting and the understanding of the causes of weather activity, because they have a strong influence on both the amount of solar energy admitted to the earth-atmosphere system, and the amount of energy returned to space from the surface.

The energy balance of the earth-atmosphere system is made up of the difference between the incoming solar radiation, mostly in the visible, and the outgoing terrestrial radiation in the infrared. The latitudinal variation of the energy balance shows an excess of incoming solar radiation over outgoing radiation near the equator, and a deficiency at the poles. It is this variation of the energy balance with latitude that drives the atmospheric heat engine.

That part of the visible radiation from the sun which is not reflected by clouds or scattered in the atmosphere reaches the surface of the earth and is absorbed then, heating the ground to a temperature in the neighborhood of 235°K. For a glowing body at a temperature of 235°K most of the energy is radiated at wavelengths in the far infrared. This infrared radiation is strongly absorbed by several constituents of the atmosphere, including water, carbon dioxide, and ozone. The absorption of infrared from the ground by these molecules heats the lower atmosphere, which re-radiated the absorbed energy, partly upward to outer space, and partly downward to provide additional heating of the surface.

The additional heating of the surface by the return of infrared from the atmosphere is referred to as the "greenhouse effect." On the earth it is sufficient to raise the temperature by about 55°K, so that the average temperature of the surface of our planet becomes 290°K.

Clouds are strong absorbers of infrared and influence the infrared transmission and the local greenhouse effect. (This is in addition to the primary effect of clouds as reflectors of incident visible solar radiation.)

Thus, the cloud cover has an important effect on the deposition of energy in the atmosphere because it influences both the inflow and the outflow of energy through the atmosphere. Thus far the characteristics of clouds -- amount, types, and approximate heights -- have all been measured by ground-based observers. Satellite observations by television cameras introduce the possibility of obtaining extensive global cloud cover data in relatively short periods of time.

A. Arking of the Goddard Institute for Space Studies and New York University has recently carried out the first statistical analysis of TIROS cloud cover data using a digitizing technique applied to TIROS III photographs. The TIROS III results are compared in Figure 2 with a climatological mean cloudiness for the Northern Hemisphere compiled by K. Telegadas and J. London, then at New York University, from ground observations extending over a 50 year period. The Southern Hemisphere data shown in the figure were compiled by H. Landsberg of the U.S. Weather Bureau.

The results in Figure 2 show that the cloud cover in middle latitudes is the same in the Northern and Southern Hemispheres. However, in tropical latitudes there is an asymmetry, with a local maximum of the cloud cover in the tropics centered at

$10^{o}N$ latitude. This is the average position of the "thermal equator" during the period 12 July to 30 September.

These results are preliminary, but the approach seems to be promising, and it is hoped that improved techniques will lead to the availability of fine-scale temporal and geographical variations in the distribution of the energy balance.

THE UPPER ATMOSPHERE

The physical processes which control the upper atmosphere are determined largely by the absorption of solar ultraviolet radiation by the atoms and molecules existing at great heights. Although the ultraviolet component of the solar radiation is only a small fraction of the total solar energy flux, the absorption cross sections in the far ultraviolet are so large that these wavelengths are effectively removed from the incident spectrum by the time the incident flux has penetrated to a height of 100 km. The ultraviolet radiation provides the principal source of heating of the thin upper air and the major determining factor in its structure.

At lower altitudes the air is composed of oxygen and nitrogen, and we can measure the proportions of these rather accurately. At the highest altitudes these gases have partially settled out of the air through diffusion. The lighter gases dominate the composition of the air at sufficiently high altitudes. Of these gases hydrogen is the lightest, and for this reason it was once believed to be the dominant constituent of the air above the oxygen-nitrogen layer. The emergence of the hydrogen atmosphere was thought to come at an altitude of about 1200 km. However, in July 1961, Marcel Nicolet of Belgium suggested on the basis of an initial examination of the density data of Echo I that between the oxygen-nitrogen atmosphere and the hydrogen atmosphere there should lie a layer of helium. The helium layer was discovered experimentally a short time later by R. Bourdeau of the NASA Goddard Space Flight Center, and has since been confirmed in other experiments. (Figure 3)

Our knowledge of atmospheric properties at altitudes of above 200 km. is mainly derived from the measurements of atmospheric drag acting on satellites. The period of revolution of a satellite decreases steadily at a rate proportional to the drag force exerted by the atmosphere, which is, in turn, proportional to air density; a measurement of the rate of change of period therefore gives the value of the air density suitably averaged around the orbit.

The detailed study of satellite drag has been a very valuable source of information on atmospheric properties. L. G. Jacchia of the Smithsonian Astrophysical Observatory was the first to discover, by careful analysis of time variations in the drag, that the upper atmosphere is extremely responsive to solar control, undergoing excursions in density which were later found to be as much as a factor of 100 and excursions in temperature by hundreds of degrees, according to the level of solar activity.

The significance of the correlation between solar activity and the properties of the earth's upper atmosphere can be understood as follows: The surface of the sun is the scene of great activity, especially during the maximum of the sunspot cycle, when it is marked by sunspots and by hot, dense regions with temperatures of some millions of degrees, which are located in the solar corona above the sunspot areas. When such an active region faces towards the earth in the course of the sun's rotation, extreme ultraviolet radiation emitted from these active regions is absorbed in the upper atmosphere. The precise correlation between solar activity and density was discovered by L. G. Jacchia of the Smithsonian Astrophysical Observatory and by W. Priester of Bonn University Observatory and the Goddard Institute for Space Studies. Their results suggest that the amount of energy transferred to the earth is sufficient to heat the atmosphere appreciably, causing an upward expansion and a large increase in the density of the exceedingly thin air at high altitudes. This discovery provided the first direct evidence regarding the influence of solar surface activity on atmospheric properties.

The continuing analysis of the correlation has given us a rather full picture of the degree of solar control over the upper atmosphere. It indicates that the atmosphere is appreciably heated by the ultraviolet emitted at times of general solar surface activity, and further heated by interaction of the earth with the clouds of solar particles, which are also emitted from the sun following solar surface eruptions. The arrival of the clouds of particles at the earth is signified by the onset of geomagnetic disturbances or "magnetic storms." It is found that increases in the temperature of the atmosphere occur shortly after the time that the magnetic storms commence. Thus, it appears that both ultraviolet radiation and corpuscular streams constitute sources of energy for the upper atmosphere. (Figures 4, 5) The question of the energy sources for the upper atmosphere is the most important single problem for upper atmosphere physics at this time. The continuing investigation of this matter and, in particular, of the roles played by particle and radiation sources, respectively, will be one of the main areas of experimental and theoretical effort in the next several years.

THE MAGNETOSPHERE

The evidence cited above suggests that corpuscular streams from the sun transfer appreciable amounts of energy to the atmosphere. The question arises as to how the transfer of energy in the atmosphere occurs.

The general answer seems to be connected with the properties of the outermost layer of the atmosphere. The density of the upper air merges into the density of the interplanetary gas at an altitude of about 100,000 km., marking the boundary of the atmosphere. Early in 1958, however, J.A. Van Allen of the State University of Iowa discovered, by analysis of geiger counter data from Explorer I, that there was an additional layer of energetic charged particles in the upper atmosphere. These charged particles are trapped in the atmosphere by the earth's magnetic field, and the atmospheric layer which they constitute is therefore called the magnetosphere.

During the last few years three important developments have substantially changed our earlier impressions about the character of the magnetically trapped particles and their geophysical effects.

First, B. O'Brien also of the State University of Iowa, using measurements from the Injun I satellite, discovered that the flux of charged particles coming down from the trapped region was so large that, if this flux consisted of previously trapped particles which had just been dislodged by solar disturbances, it would drain the whole magnetosphere in about an hour. He also found that when a solar disturbance occurred, both the flux of untrapped descending particles and the number of trapped particles increased. Thus, he concluded that the leakage of trapped particles from the Van Allen belts cannot be the principal source of the electrons which pass down through the atmosphere. He decided that while a few charged particles are trapped, during or after a solar disturbance, most pass directly into the atmosphere without spending an appreciable amount of time in the trapped region. Apparently, the charged particles which are observed in auroral displays and other atmospheric phenomena are those which come directly down the lines of force into the atmosphere.

Second, a large population of low energy protons, having a range from 100 kev to several mev, was discovered by A. H. Davis and J. M. Williamson of the Goddard Space Flight Center. The concentration of these protons peaks at 3.5 earth radii. At that point their density is about $1/cm^3$. This value of the trapped proton density has interesting implications. As a result of the magnetic field gradient and curvature effects, the trapped protons drift westward in the magnetic field, with an associated electric current that produces magnetic effects. These have been calculated by S. Akasofu of the University of Alaska and S. Chapman of the Universities of Colorado and Alaska and, in an unpublished work, by R. A. Hoffman of the Goddard Space Flight Center. They find that the changes in the intensities of these trapped protons produce magnetic perturbations large enough to explain most magnetic storms observed on the earth and also the very large perturbations of the geomagnetic field in space in the neighborhood of the proton belt. The relation between the trapped proton drift current and the geomagnetic storms was suggested by S. F. Singer of the University of Maryland in 1956.

The third development was the discovery of a substantial flux of electrons with very high energies, in the neighborhood of 1 million volts, at the distance of 3 or 4 earth radii, presumably produced by beta decay of albedo neutrons resulting from cosmic ray interactions in the atmosphere. These electrons penetrate the geiger counters with high efficiency; and when allowance is made for their presence, the estimate of the total flux of electrons is reduced from the early estimate value of $10^{10}/cm^2/sec/steradian$ to the current value of $10^8/cm^2/sec/steradian$.

THE MAGNETOPAUSE

The connection between the magnetosphere and the transfer of corpuscular energy to the atmosphere is probably to be found in the properties of the atmosphere near the magnetopause, the boundary separating the interplanetary medium from the region around the earth in which the geomagnetic field is dominent. The sharply defined surface of the magnetopause marks the termination of both the trapped particle region and the geomagnetic field. Satellite measurements of the geomagnetic field by L. J. Cahill of the National Aeronautics and Space Administration and of the University of New Hampshire show that the magnetopause has a thickness on the order of 100 km and occurs at a distance of 8-10 earth radii on the sunlit side of the earth.

The sharpness of the magnetospheric boundary is illustrated by Figures 6 and 7. Figure 6 represents the magnetic field measurements we obtained by Cahill and P.G. Amazeen of the University of New Hampshire using a three-component magnetometer flown on Explorer 12. At the magnetopause a sudden drop occurs, and outside the magnetosphere the magnetic field is highly variable in magnitude and direction. Figure 7 shows the counting rates of charged particle detectors flown on Explorer 14 by Van Allen, L. A. Frank, and E. Macagno of the State University of Iowa.

The detector which accepts the particles of lowest energy is labeled 213A and its counting rate reflects principally the flux of 50 kev electrons. At the magnetopause the counting rate of this detector drops by a factor of approximately 20 to a value which is approximately independent of altitude and produced by the cosmic ray background in space.

Within the magnetopause there are no substantial fluxes of energetic particles other than those of the magnetically trapped particles illustrated in Figure 8. Detectors flown on Mariner II indicate that the sun is the source of a particle stream which flows through interplanetary space continually, although with variable velocity and intensity. The Mariner II detectors, and also the plasma probe flown on Explorer 10 by B. Rossi, H. S. Bridge, A. J. Lazarus, A. Bonetti and F. Scherb of the Massachusetts Institute of Technology, have shown that these particles move radially outward from the sun at velocities varying from 300 to 600 km/sec and at an average flux of $10^8/cm^2/sec$ outside the magnetopause. The interplanetary stream of solar psrticles, called the solar wind, cannot penetrate the magnetic field of the earth but divides and flows around it as the waters of a stream divide around a boulder. (Figure 8) The closest distance of approach of the solar wind to the earth is about 10 earth radii.

The shadow or cavity carved by the magnetic field of the earth in the solar wind should, in principle, extend back indefinitely far into the solar system behind the earth. However, because the particles of the stream have appreciable transverse velocities associated with their thermal motions, we expect these particles to diffuse together eventually in the shadow of the earth. The ratio of mean transverse to radial velocities is about ¼, hence we expect the geomagnetic cavity to be filled in at a distance of four times the diameter of the cavity, or roughly the distance of the moon from the earth, as suggested in Figure 8.

The transfer of energy from the solar wind to the atmosphere within the cavity is difficult to estimate. The variable magnetic fields in the solar plasma are believed to glue the particles together and give their motion the properties of fluid flow, in spite of the low density, with turbulence therefore to be expected at the region of impact of the solar wind on the magnetopause. The buffeting of the magnetospheric boundary associated with this turbulent impact may generate disturbances in the field just within the magnetopause. These disturbances propagate hydromagnetically down or across the field lines into the atmosphere, where they transfer energy which may appear as atmospheric heating, ionization, auroral disturbances and magnetic storms -- that is, the whole complex of disturbances produced in the atmosphere at high geomagnetic latitudes in times of solar activity.

Another aspect of the interaction of the solar plasma with the magnetosphere is the expectation that a "shock wave" will be formed some distance beyond the actual magnetopause. This arises from the supersonic flow of the plasma and the necessity that such flow must become subsonic in the vicinity of the earth. The transition requires a shock wave to be set up, which stands off some distance from the magnetopause and has a thickness determined by the ability of the magnetic field to change the bulk motion of the plasma particles. Evidence of the perturbed magnetic fields corresponding to the shock wave and the intervening transition region has been detected by N. F. Ness of the Goddard Space Center with magnetometers flown on the Interplanetary Monitoring Platform (IMP) spacecraft launched on November 27, 1963.

THE ATMOSPHERE OF VENUS

Venus is the third brightest object in the sky, the nearest planet to the earth, and the planet most closely representing the earth in size and mass. It has been studied with the telescope since Galileo's time and yet it remains an enigma, because its surface is permanently shrouded by a layer of clouds. In this state of ignorance, hope has flourished that Venus offers a hospitable environment for the development of advanced forms of life.

However, some information regarding the surface of the planet has been obtained in recent years by the study of the microwave radiation emitted in the long-wave region of its thermal spectrum. This radiation, with wavelengths in the region of one to ten centimeters, penetrates the clouds without significant attenuation; its intensity is proportional to the temperature of the emitting surface.

The first attempts to measure the microwave radiation from Venus were made in 1956 with the Naval Research Laboratory radio telescope. The temperature inferred from the measured radiation intensity was approximately 600° K, or 700° F, and certainly too hot to permit any terrestrial forms of life. Repeated measurements have confirmed the NRL results and have forced a revision of our ideas regarding the surface and lower atmosphere of Venus.

It is difficult to understand why the temperature of Venus should be so much higher than that of the earth. Our path to an explanation would lie in the assumption of an extremely dense atmosphere which absorbs strongly in the infrared region of the spectrum but is transparent to visible radiation. The part of the incident sunlight which is not reflected back by the clouds will therefore penetrate through the atmosphere and heat the surface of the planet. But when the surface layers reradiate this energy at infrared wavelengths, the radiation is absorbed by the atmosphere and returned in large measure to the surface, thus giving an additional flux of energy into the ground and raising its temperature. This atmospheric phenomenon is analogous to the action of the glass panes of a greenhouse, and is called the "greenhouse effect."

The clouds of Venus reflect three-quarters of the incident sunlight; the remaining quarter of the incident radiation would bring the surface to a temperature of 235° K, if there were no atmospheric greenhouse effect. If the greenhouse effect is to raise the ground temperature to 600° K, the optical thickness of the atmosphere must be 50 mean free paths throughout the far infrared region. In an atmosphere with this degree of opacity, only one photon in 10^{21} escapes directly, without absorption. This condition is so severe that alternative suggestions have been made, among them being the hypothesis that the apparently high radio temperature of Venus was the result of microwave emission from its ionosphere rather than from the surface.

The Mariner II Venus fly-by launched on August 27, 1962 included experiments designed to test this hypothesis. This spacecraft passed Venus at a distance of 20,900 miles on December 14, 1962, and made crucial measurements of the temperature across the disc. The spacecraft was equipped with two sets of radiation detectors, one in the infrared and one in the microwave region. Measurements of the radiation emitted by the planet in the microwave region included the 19 millimeter wavelength, which passes through the atmosphere with little attenuation and hence provides a measure of the temperature at the ground, provided there is no additional emission from the ionosphere. A modest degree of atmospheric attenuation is, however, to be expected, and in the scan of Mariner II across the disc of the planet, this slight degree of attenuation should show up as a lower intensity of measured radiation at the edge or limb of Venus, where the thickness of the intervening atmosphere is greater. However, if the high microwave intensities and apparent temperatures result from emission by electrons in the ionosphere of Venus, then the readings at the limb should indicate an enhancement or brightening because of the greater thickness of the ionosphere in line of sight.

The Mariner II results showed a conclusive darkening of the limb of Venus at 19 millimeters, thus eliminating the possibility of ionospheric emission and confirming that the measured radio temperature of 600° K is associated with the surface of the planet.

EXPLORATION OF THE MOON

The moon is a uniquely important body in the study of the history of the solar system because its surface has preserved the record of its history remarkably well. The moon has a negligible atmosphere and no oceans. It is, therefore, unchanged by the processes of erosion which erase the history of the earth's surface in a relatively short period of time -- between ten and thirty million years.

This is evidenced, in part, by the tens of thousands of craters on the lunar surface, produced by the impact of meteorites which presumably have been colliding with the moon since its formation. This is perhaps the only physical record which we have of events in the development of the solar system going back to that early time.

Because of this antiquity of the moon's surface, there is another remarkable record preserved -- a layer of cosmic dust which is believed to have rained on it from the solar system since its formation. This dust may be as much as a foot or more in depth and may contain organic molecules and the precursors of life on earth.

The most important measurements of lunar properties from spacecraft have resulted from Russian flights of Lunik II and

Lunik III. From the Lunik II magnetometer data Soviet scientists concluded that an upper limit of approximately 100 gammas could be placed on the moon's magnetic field. In future flights, improvements on this limiting value of the moon's magnetic field may provide information on the presence or absence of a liquid core within that body: on the earth the magnetic field is supposed to be associated with currents in the liquid core of the planet. This in turn could have a bearing on our understanding of the formation of the moon and similar bodies in the solar system.

Lunik III has provided us with the first pictures of the remote side of the moon. In spite of some blurring, the photographs are still of great interest, for it is possible to distinguish a large number of features resembling the craters and maria on the front face. Perhaps the most interesting feature is the Soviet Mountain Range, a chain extending across the center of the moon's hidden face. It resembles the great ranges on the earth and is unlike the mountain formations characteristic of the moon's front face which seem to be circular crater walls and deposits of debris formed by the impact of large meteorites on the lunar surface.

According to our present ideas, terrestrial mountains result from the combined effects of erosion and wrinkling of the earth's crust, while these mountain-building forces have

SOLAR PHYSICS

One of the most interesting questions in solar physics is the manner in which energy is transported above the surface of the sun to heat the chromosphere and corona.

We know that near the center of the sun, where the temperature is approximately 15 million degrees Kelvin, hydrogen is converted into helium by a variety of nuclear reactions. We also know that the sun is a self-adjusting system which expands or contracts in order to maintain a precise balance between the energy generation at the center and the energy emission from the surface.

All regular mechanisms of energy transport can carry heat only from a region of high temperature to a region of low temperature. Therefore, in order to carry away from the center of the sun the heat generated by nuclear reactions, it is necessary for the temperature to fall continuously from the center to the edge. This is in fact the case, the temperature falling from 15 million degrees at the center to 5800° at the visible edge of the sun.

However, above the visible edge, which is called the photosphere, there lies a relatively tenuous region of gas which constitutes the atmosphere of the sun. This region is divided into the chromosphere, and above that, the corona.

been much less effective on the moon. The markings of the Soviet Mountain Range could have resulted from the running together of several obscured but independent markings. However, if they continue to appear as a single range in later, more detailed pictures, we may have to revise our theories of lunar structure.

The puzzling fact about these circumstances is that the temperature of the sun <u>rises</u> again from the photosphere, reaching a value of 1.5 to 2 million degrees in the corona. One of the burning questions of solar physics is what constitutes the source of the energy which produces the very high temperatures in the solar corona. Also what is the mechanism of energy transport which can carry energy without appreciable losses through the dense gases of the photosphere and yet undergo strong losses in the tenuous regions of the corona.

A current belief is that a wave motion -- either a sound wave, a hydromagnetic wave, or a gravity wave -- carries energy upward from the photosphere and deposits it into the corona. When a sound wave propagates into a region of decreasing density, its amplitude increases and it will steepen into a shock wave. This is a mechanism in which considerable energy dissipation takes place. It appears that hydromagnetic waves are rapidly damped out below the photosphere, but if they can be generated in the region of the chromosphere, then they would not tend to be dissipated until the waves have reached the corona. Magnetic disturbances above the photosphere may be particularly effective in generating these waves. Gravity waves consist of a kind of rolling motion similar to the waves on the surface of the ocean. These may, like sound waves, be generated by the motions of convecting material in the transition layer; they will have a vertical component of propagation and will be dissipated in the corona.

It may be that all three of these mechanisms are effective for the heating of the chromosphere and corona. If this is the case, there may be a steady heating of the corona upon which is superimposed a localized heating associated with magnetic activity. Thus, the heating of the corona is expected to depend upon the magnetic structure in the outer layers of the sun. This is observed in many phenomena. In particular, in sunspot regions where the magnetic field strengths are higher than is normal on the sun's surface, both the chromosphere and the corona have a higher than normal temperature.

The behavior of the chromosphere and the corona is most easily observed by studying the ultraviolet emission from the sun, since in the ultraviolet region the amount of light emitted from the photosphere greatly decreases, whereas the higher temperatures in the chromosphere and corona are responsible for the presence of large numbers of emission lines. The most important emission lines are due to hydrogen and helium. In order to understand solar surface physics in more detail, it is essential to obtain observations of the time variations of these emission lines as indicators of the time variations of behavior in the chromosphere and corona.

The first experiments in this direction were very successfully accomplished by the flight of the first Orbiting Solar Observatory, which was launched on March 7, 1962. It gave several months of data, continuously monitoring a number of different wavelength regions for emission from the sun.

Particularly interesting are the data for the time interval 11th through 22nd of March, 1962. At the beginning of this period the sun was in an exceptionally quiet condition, but as the period progressed the sun became more and more active, until on March 22nd there was a flare of importance 3. Experiments revealed that the Lyman alpha line of He II at 304 Å increased by some 33% during the interval, and during the flare itself the line increased by an additional 14%. The lines of Fe XV at 284 Å and Fe XVI at 335 Å also increased in intensity by a factor of four. At longer wavelengths, the Lyman alpha line of hydrogen was observed to increase in intensity by 6.8% during the flare.

Very interesting results were also obtained in the x-ray region, 1-10 Å. During the quiet period a flux was observed which was 360 times the theoretical background which would be obtained from a corona at a temperature of 1.8×10^6 °K. This indicates that nonthermal processes are present and important in the corona under even the quietest solar conditions.

A continuing series of Orbiting Solar Observatories is planned in which these interesting phenomena can be monitored continuously during future years.

X-RAYS AND GAMMA RAYS

The space research program is not confined to the discovery of new facts about the solar system. It also represents an important opportunity for the astrophysicist to extend his knowledge of more distant parts of space through observations at wavelengths for which photons do not penetrate through the atmosphere. The principal regions involved are the x-ray and gamma ray region, the ultraviolet, the infrared, and long wavelength radio waves. The early rocket and satellite measurements of x-rays and gamma rays have been particularly interesting to physicists because they suggest several possible new types of phenomena in space.

X-rays and gamma rays can be produced by a variety of high energy processes. These processes include collisions between high energy nucleons which can create neutral pions, which in turn decay to give gamma rays exceeding 50 mev in energy. Fast electrons can produce x-rays or bremsstrahlung when they pass close to a nucleus. Fast electrons can also collide with photons of visible starlight and increase the energy of the photons into the x-ray and gamma ray region. If radioactive nuclei are produced and dispersed in space between the stars, then some of them should emit characteristic gamma ray energies which might be detected. If positrons are produced in dense regions of matter, such as stellar surfaces, then upon being slowed down and annihilated they will emit the characteristic gamma rays of 0.51 mev energy. If neutrons are produced near stellar surfaces and are slowed down and captured by the overwhelmingly abundant hydrogen that is present, then these will provide characteristic capture gamma rays with an energy of 2.31 mev. Finally, we may note that if objects should exist in space with surface temperatures of some millions of degrees Kelvin, then photons in the x-ray region will be emitted by thermal processes from their surfaces.

Preliminary measurements now exist of the fluxes of x-rays and gamma rays in a number of different energy intervals. A general background of x-rays of a few kev energy was observed in a rocket flight by R. Giacconi, H. Gursky, F. R. Paolini, of American Science and Engineering, Inc., and B. B. Rossi of the Massachusetts Institute of Technology. A general background radiation of gamma rays in the region near 1 mev energy was measured in the Ranger 3 flight by J. R. Arnold of the University of California, LaJolla, A. E. Metzger, of the California Institute of Technology, and E. C. Anderson, and M. A. Van Dilla, Los Alamos. A small but still significant flux of gamma rays with energies exceeding 50 mev was observed with the Explorer XI gamma ray satellite by W. L. Kraushaar and G. W. Clark of the Massachusetts Institute of Technology.

A number of attempts have been made to explain the presence of these background x-rays and gamma rays. Most mechanisms thus far examined appear quantitatively inadequate to explain the observed fluxes. One promising explanation is due to J. E. Felten and P. Morrison of Cornell University who suggested the importance of the inverse Compton effect in which the high energy electrons present in the cosmic rays collide with photons with energies of the order of 1 electron volt which are emitted from stars. Following such a collision, the photons can easily be raised to the observed range of x-ray and gamma ray energies, depending upon the energies of the electrons with which they collide. Calculations by Felten and Morrison were based on this effect. (Figure 9) A flux will be emitted by the outer halo region of our galaxy if the observed flux of high energy electrons at the position of the earth exists throughout this large outer region of the galaxy. Electrons in the halo fail to account for the observed x-ray and gamma ray fluxes by some 2½ orders of magnitude. However, if it were to be assumed that the high energy electrons are present throughout all of space with the same intensity with which they are observed near the earth, then a background of some 30,000 times that which would be produced within the galactic halo would be observed. Evidently, such high fluxes of electrons cannot exist throughout all of space. One per cent of such a flux of electrons can be expected to give a background of x-rays and gamma rays which fits the observations very nicely.

However, perhaps the most interesting questions concerning the celestial x-rays have been raised through the discovery of discrete sources by Rossi and his colleagues and by H. Friedman, S. Bowyer, T. A. Chubb, and E. T. Byram of the Naval Research Laboratory. Both groups have observed a strong x-ray source in Scorpius which is not coincident with any conspicuous object. Friedman has suggested that this object is a neutron star having a surface temperature of several million degrees and that the x-rays are due to thermal emission from the surface layers. Rossi and his colleagues have determined from atmospheric absorption measurements that if the Scorpius source has a thermal spectrum its temperature is approximately 8×10^6 °K. Friedman and his colleagues have also observed x-rays from the direction of the Crab Nebula, the remnant of the supernova explosion of 1054 A. D. (Figure 10)

Neutron stars are hypothetical objects which form one class of degenerate stars, the other class being the degenerate white dwarf stars, which are observed. A typical density for matter in a white dwarf star is 10^6 gm/cm^3, and the electrons form a degenerate gas which exerts sufficient pressure to maintain the stars against further contraction. If mass were to be added to such a star, the central region would have to become denser in order to supply the additional pressure required to support the additional mass. There is a relativistic upper limit to the mass of white dwarf stars, but before this limit is reached, the energies of the degenerate electrons have become so high that the nuclei are forced to undergo multiple electron capture reactions, and the nuclei dissolve mainly into neutrons, with only enough protons and electrons left to prevent the neutrons from undergoing their usual mode of decay into electrons and protons.

At 10^{15} gm/cm^3 or more, densities comparable to those in the atomic nucleus, this neutron-rich nuclear matter itself becomes degenerate, and it is expected that stable stars could be constructed of it. Such stars may be formed in the central regions of more massive stars when these stars undergo supernova explosions and blow off most of their mass. Recent work by D. Morton of Princeton University, E. E. Salpeter of Cornell University, H. Y. Chiu, S. Tsuruta, and A. G. W. Cameron of the Goddard Institute for Space Studies indicates that the surface temperature of a neutron star is likely to lie between one and two orders of magnitude below its central temperature. Thus, if such stars are formed with central temperatures over 10^9 ^oK, as would likely be produced in a supernova explosion, then their surface temperatures are likely to be many millions of degrees for several thousand years.

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FIGURE 1

Geoid heights (in meters) relative to an ellipsoid with a flattening of 1/298.3: Major features include a negative anomaly in the Indian Ocean and a positive anomaly centered near Indonesia and the Philippines. (from MacDonald, G. J. F., Science, 143, 923 (1964))

FIGURE 1

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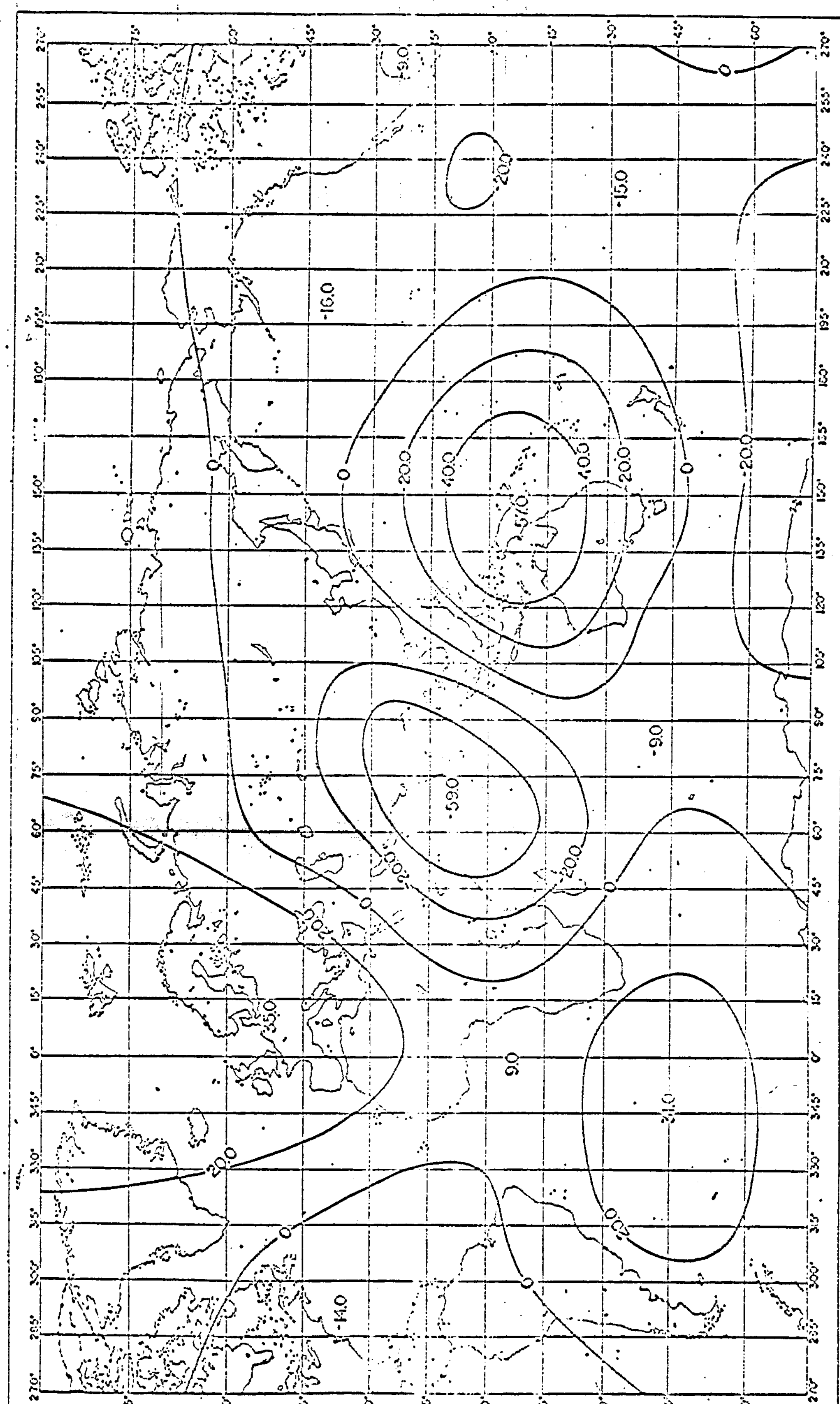
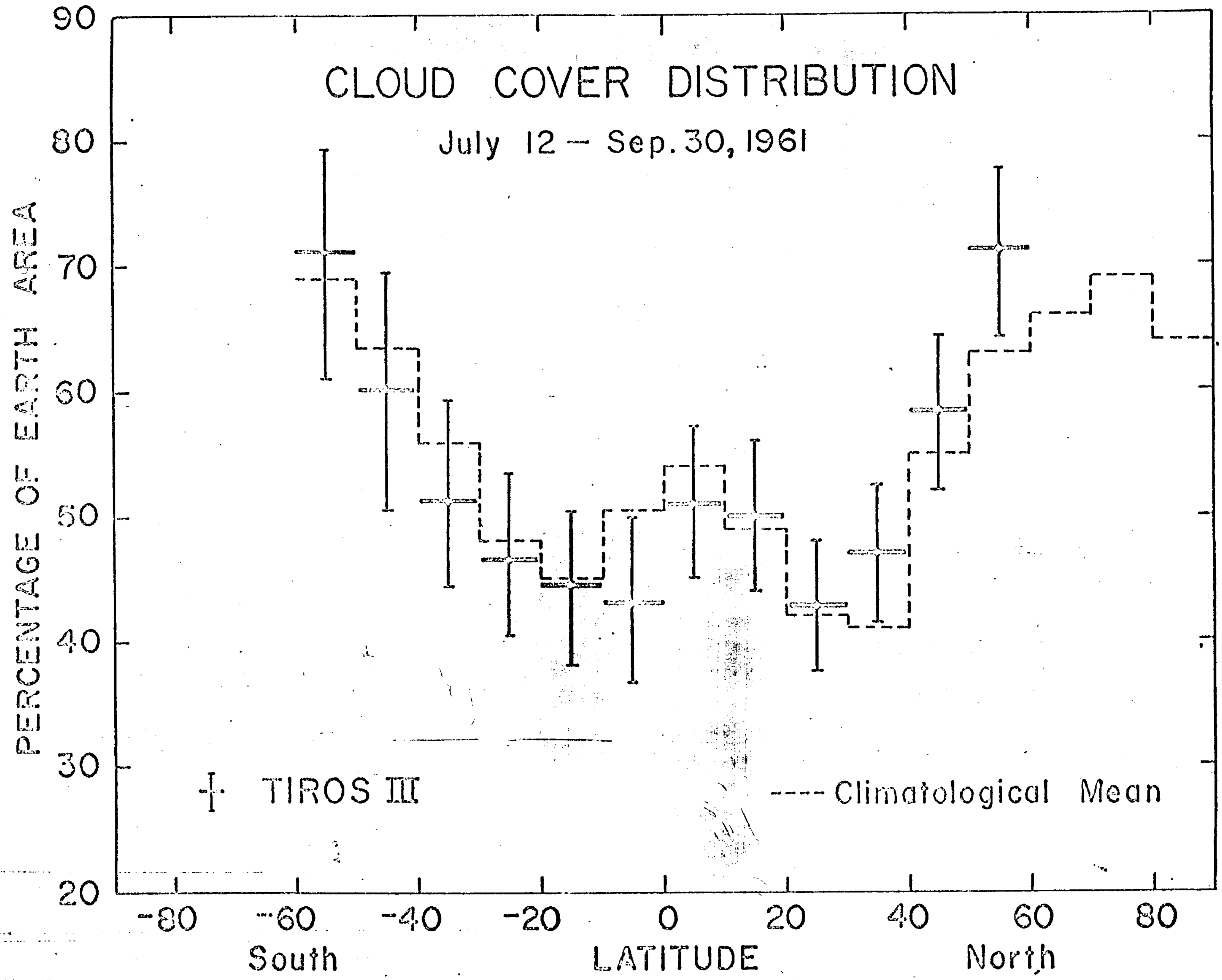


FIGURE 2

The latitudinal distribution of cloud cover: The solid horizontal bars are the results derived from TIROS III photographs from 12 July to 30 September 1961. The vertical lines show the estimated uncertainty in the TIROS-derived data. The dashed histogram represents the climatological mean cloud cover derived from ground observations, as compiled by Telegadas and London for the Northern Hemisphere and by Landsberg for the Southern Hemisphere. The broad features of the latitudinal distribution are consistent with the known pattern of the general circulation. The air rising at the thermal equator produces a relative maximum in the cloud cover, while on the average there is downward motion of cool, dry air at 30° north and south of the thermal equator, which explains the relative minimum of cloudiness.

(from Arking, A., Science, <u>143</u>, 571 (1964)

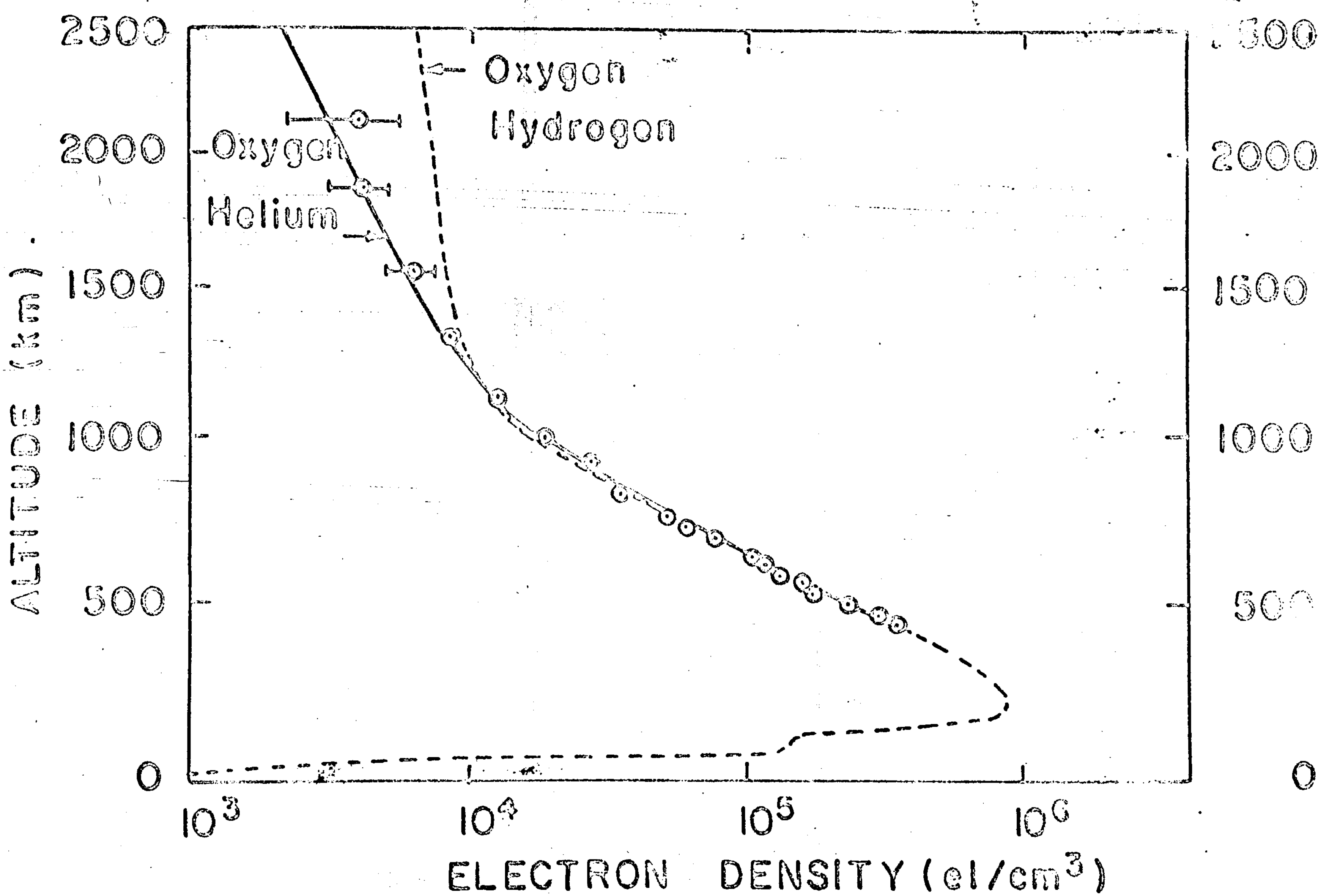


CLOUD COVER DISTRIBUTION
July 12 – Sep. 30, 1961
PERCENTAGE OF EARTH AREA
90
80
70
60
50
40
30
20
-80
-60
-40
-20
0
20
40
60
80
South
LATITUDE
North
TIROS III
Climatological Mean

FIGURE 3

Electron density profile measured by a Scout rocket, and providing evidence for a helium layer in the upper atmosphere: The dotted line is the density distribution for a scale height derived from an oxygen-hydrogen mixture. The full line is the calculated density distribution for an oxygen-helium mixture.

(from Bauer, S.J., and J.E. Jackson, Journal of Geophysical Research, 67, 1676 (1962)



Oxygen
Hydrogen
Oxygen
Helium
ALTITUDE (km)
2500
2000
1500
1000
500
0
ELECTRON DENSITY (el/cm^3)
10^3
10^4
10^5
10^6

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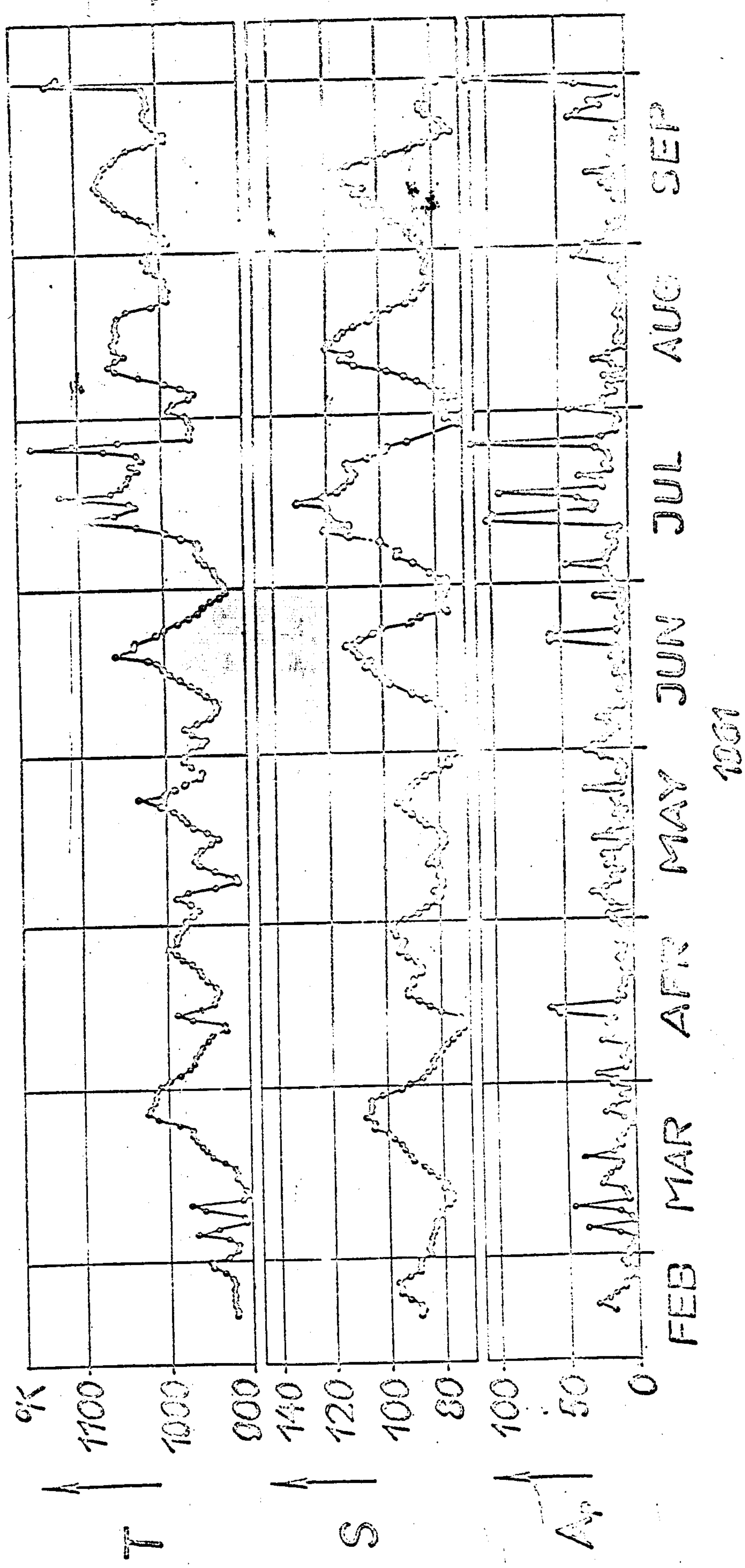
FIGURE 4

Temperature variation correlated with solar radio emission and geomagnetic indices for the time interval from February through September 1961: The upper curve gives the exospheric densities and temperatures, derived from Explorer 9 drag measurements by L.G. Jacchia and J. Slowey (1962). The middle curve represents the flux of the solar radiation at 20 cm wavelengths, an indicator of solar activity, measured at the Heinrick Hertz Institut at Berlin. The lower curve gives the geomagnetic activity index (A_p). (Courtesy of W. Priester)

(The Explorer 9 data are adapted from Jacchia, L.G., and J. Slowey, Smithsonian Astronomical Observatory Special Report, No. 84, (1962) 18 pp.)

FIGURE 4



T
S
A_p
°K
1100
1000
900
140
120
100
80
100
50
0
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
1961

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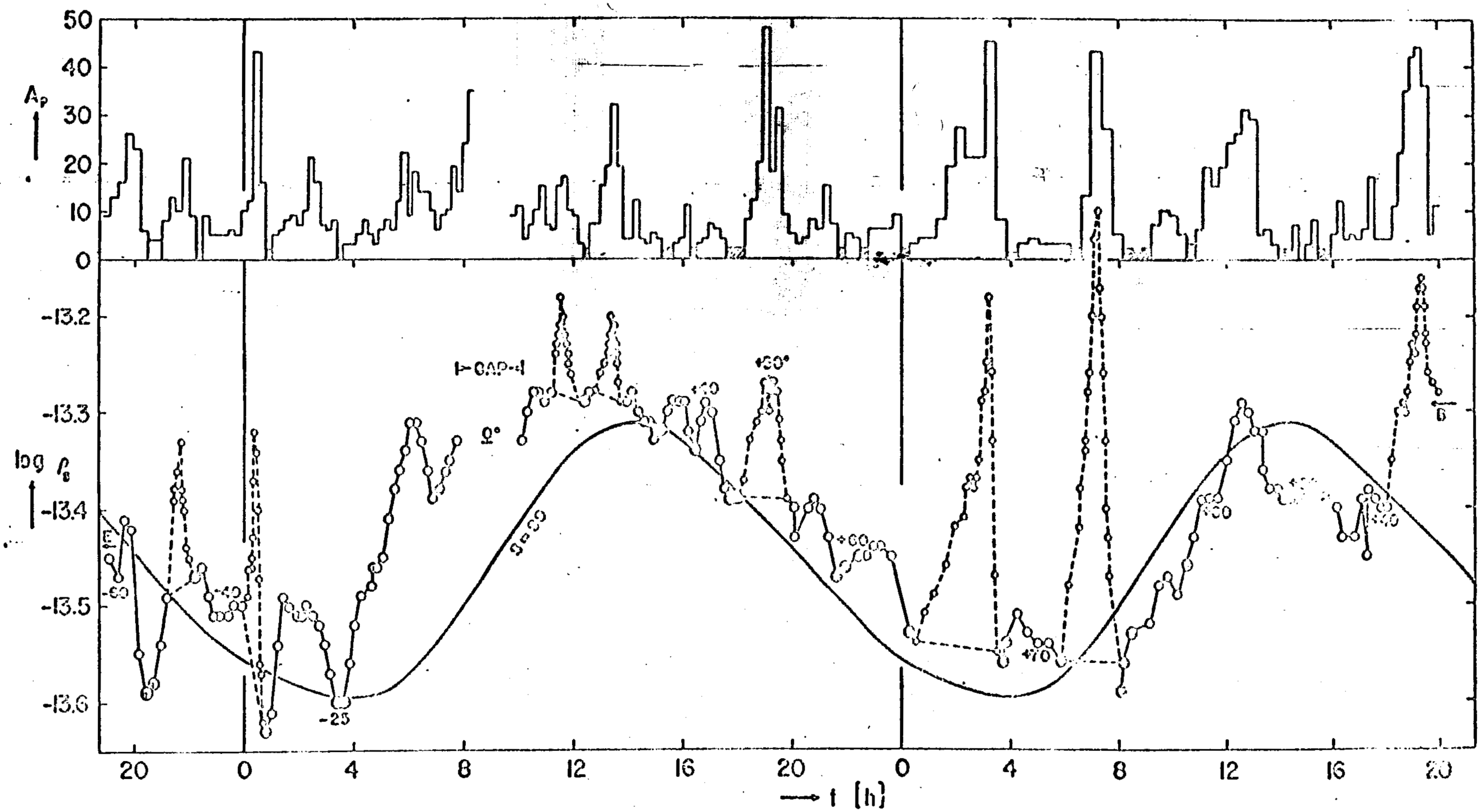
FIGURE 5

Density variations at an altitude of 250 km above sea level as function of local time t, determined from accelerations of the satellite Injun III by L.G. Jacchia and J. Slowey (1963) from December 15, 1962 through June 29, 1963: During this time the geographic latitude of the perigee covers the range from +70° to -60° as indicated by the numbers on the denisty curve. The solid curve represents the Harris-Priester model for the proper level of solar activity. The histogram in the upper part gives the daily geomagnetic indices A_p. The open circles represent the densities during magnetic storms. The solid circles represent the densities during magnetically quiet days ($A_p < 2$). The response of the atmosphere to solar activity, as indicated by violent solar storms is much greater within the auroral zone than outside this zone.

(adapted from Jacchia, L.G. and J. Slowey, Journal of Geophysical Research, 69, 905-10 (1964)



A_p
log ρ_s
t [h]
1-CAP-1
-25
+30°
+70

FIGURE 6

Explorer 12 measurements showing the abrupt termination of the geomagnetic field at the magnetopause: F is the magnitude of the magnetic field and α and ψ refer to its direction. Within the magnetosphere the field is closely described by the high altitude extrapolation of the earth's approximately dipole field, shown as the solid curve. Outside the magnetopause, which occurred at 8.2 R_E during this flight, the field is variable in magnitude and direction.

(from Cahill, L.J. and P.G. Amazeen, Journal of Geophysical Research, 68, 1841 (1963)

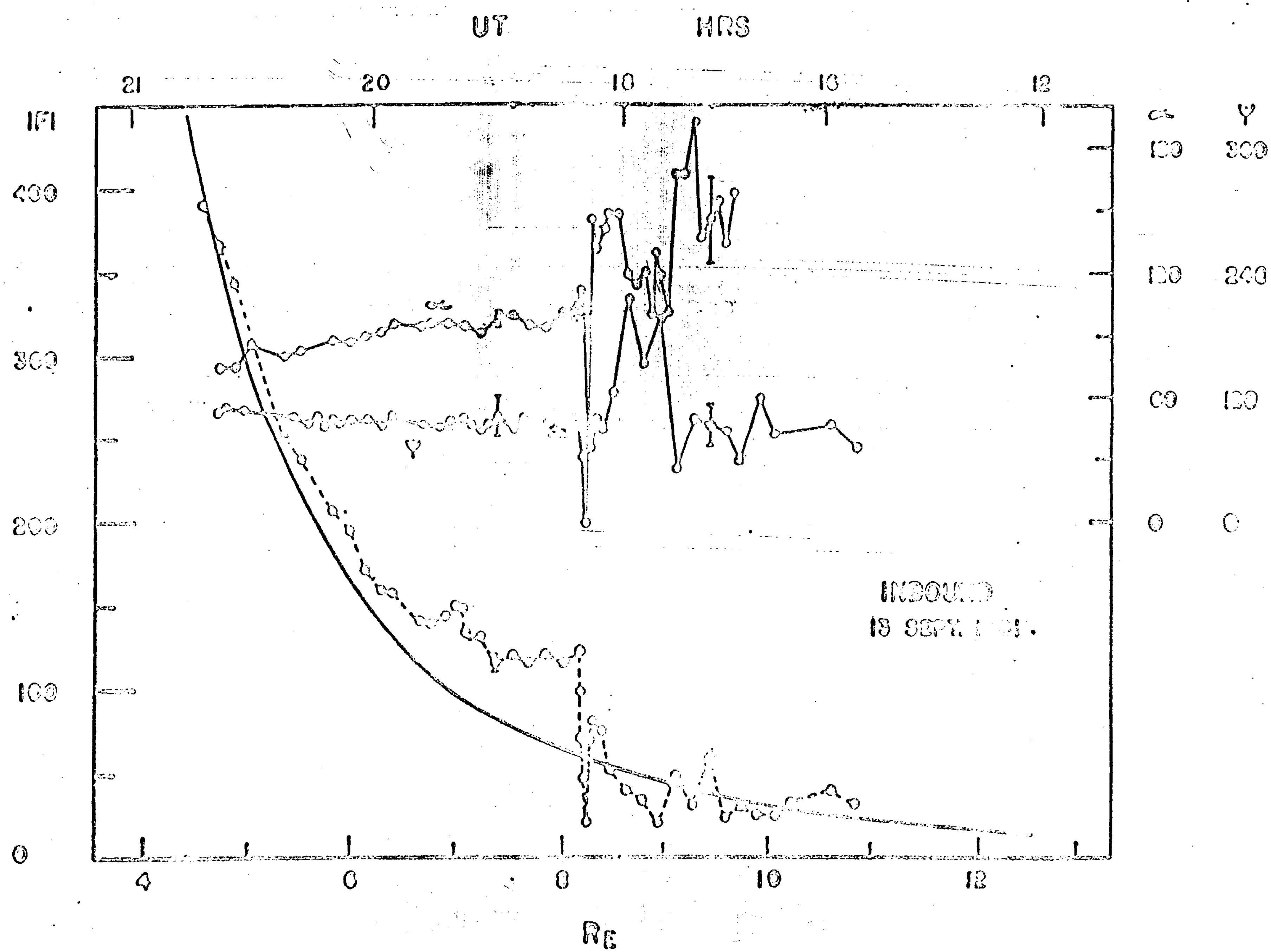
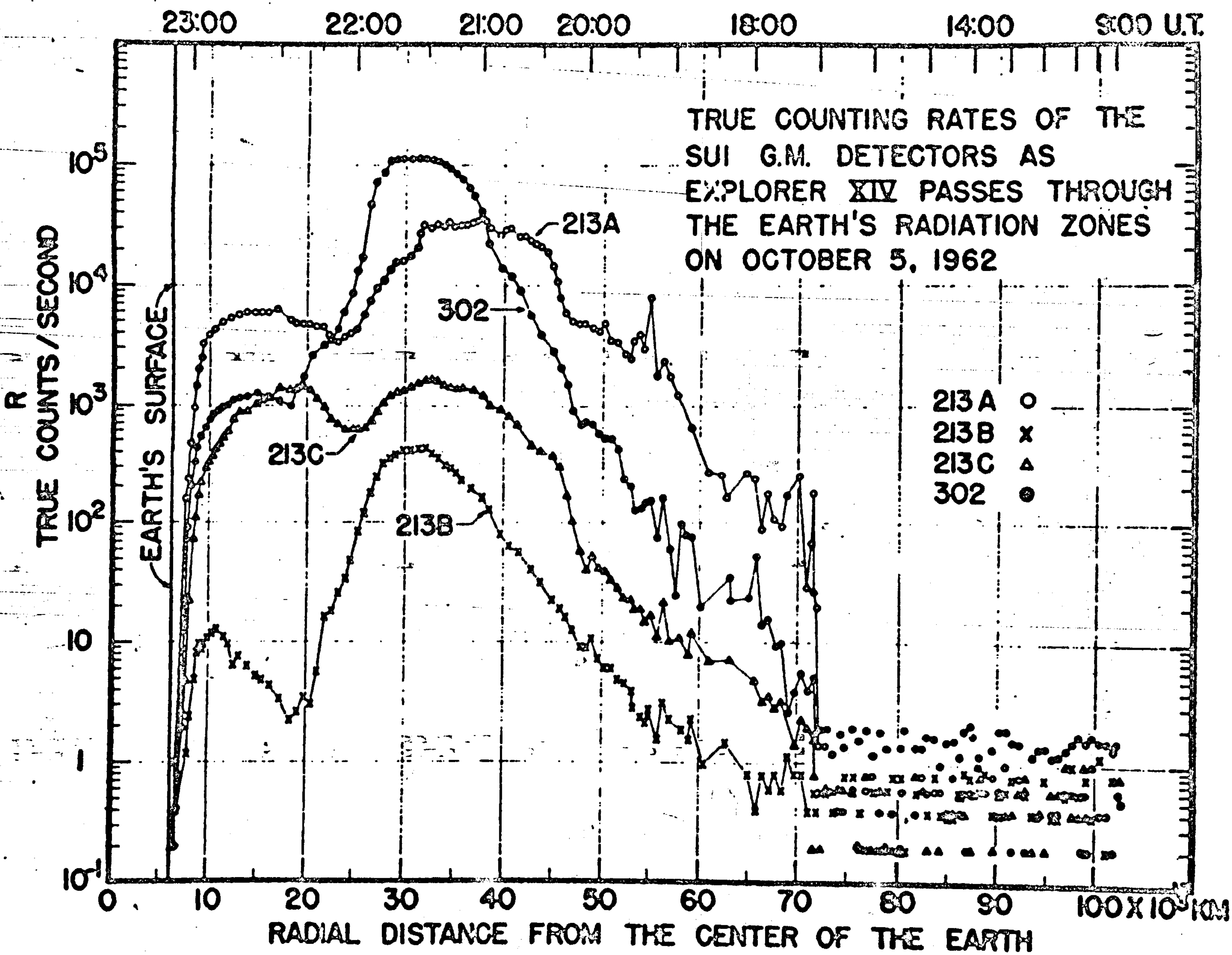

UT HRS
|F|
α
Y
Re

FIGURE 7

Explorer 14 data showing the abrupt termination of the magnetically trapped particle belts at the magnetopause. The lowest detector labled 213 A, records principally 50 kev electrons. Its counting rate drops sharply at a radius of 72,000 km. or 12.5 R_E, which corresponds to the location of the magnetopause during this flight.

(from Frank, L.A., J.A. Van Allen, and E. Macagno, Journal of Geophysical Research, 68, 3545 (1963)



TRUE COUNTING RATES OF THE
SUI G.M. DETECTORS AS
EXPLORER XIV PASSES THROUGH
THE EARTH'S RADIATION ZONES
ON OCTOBER 5, 1962
213 A o
213 B x
213 C △
302 ●
213A
302
213C
213B
EARTH'S SURFACE
23:00
22:00
21:00
20:00
18:00
14:00
9:00 U.T.
R
TRUE COUNTS/SECOND
10^5
10^4
10^3
10^2
10
1
10^{-1}
0
10
20
30
40
50
60
70
80
90
100 X 10^3 KM
RADIAL DISTANCE FROM THE CENTER OF THE EARTH

Robert Jastrow

FIGURE 8

The geomagnetic cavity in the solar wind.

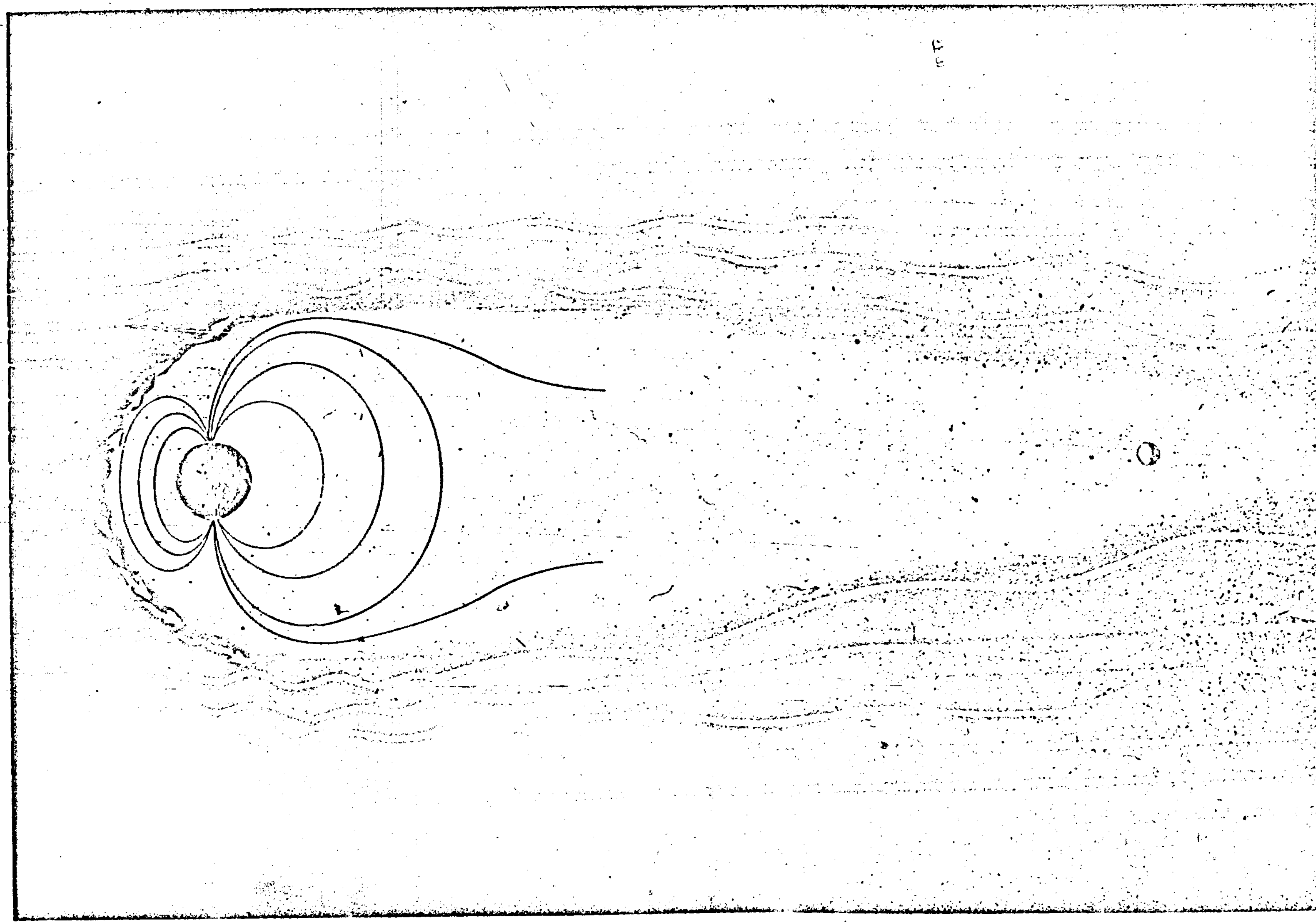


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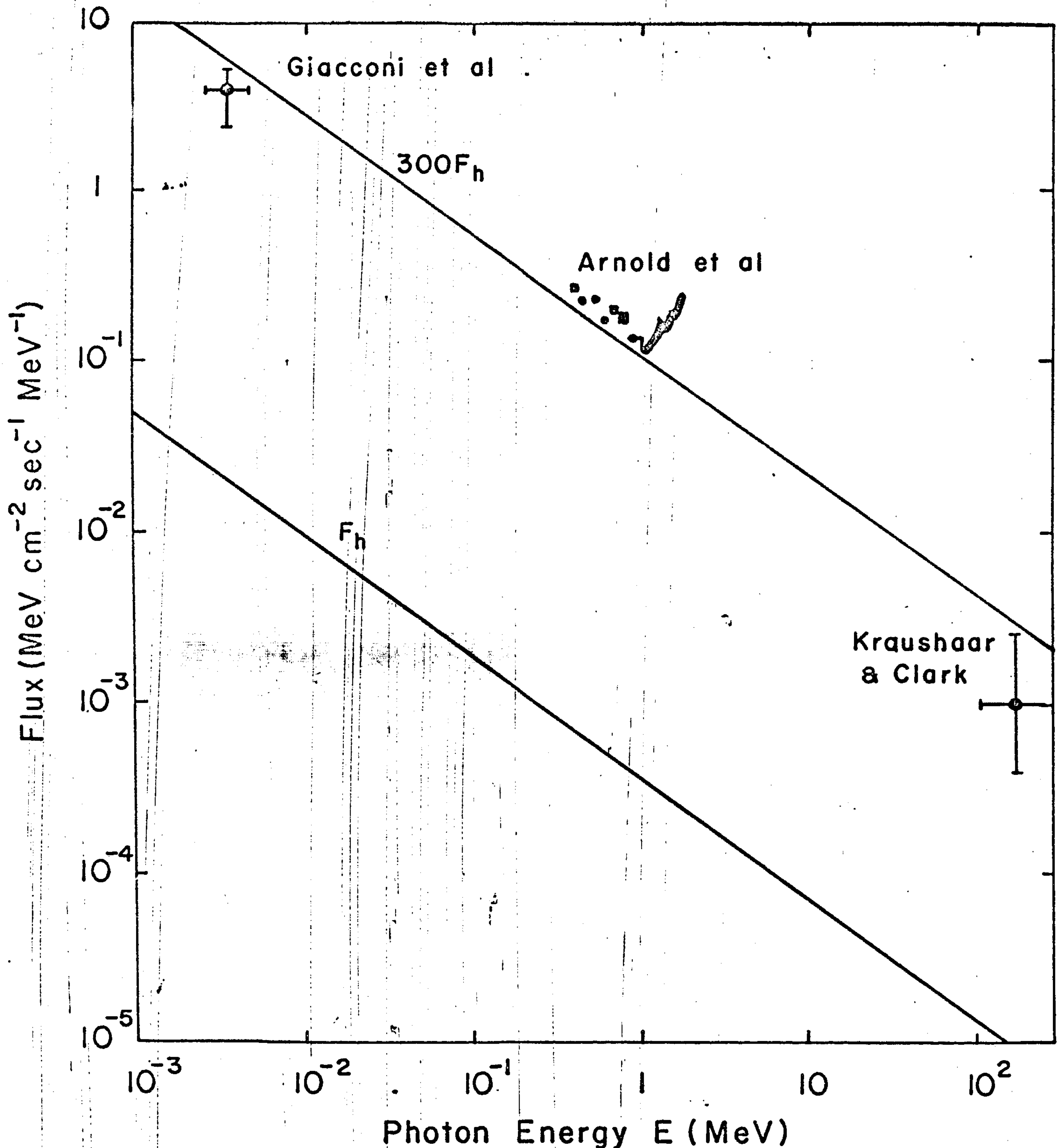
FIGURE 9

Data on hard photon fluxes in space, compared with theoretical recoil spectra: The data points are as plotted by Felten and Morrison. F_h is the expected contribution from scattering in our galactic halo. The upper line shows a flux 300 times greater, but still two orders of magnitude less than would be obtained if the electrons in our galactic halo extended throughout the intergalactic space.

(from Felten, J.E., and P. Morrison, Physical Review Letters, 10, 455, (1963)

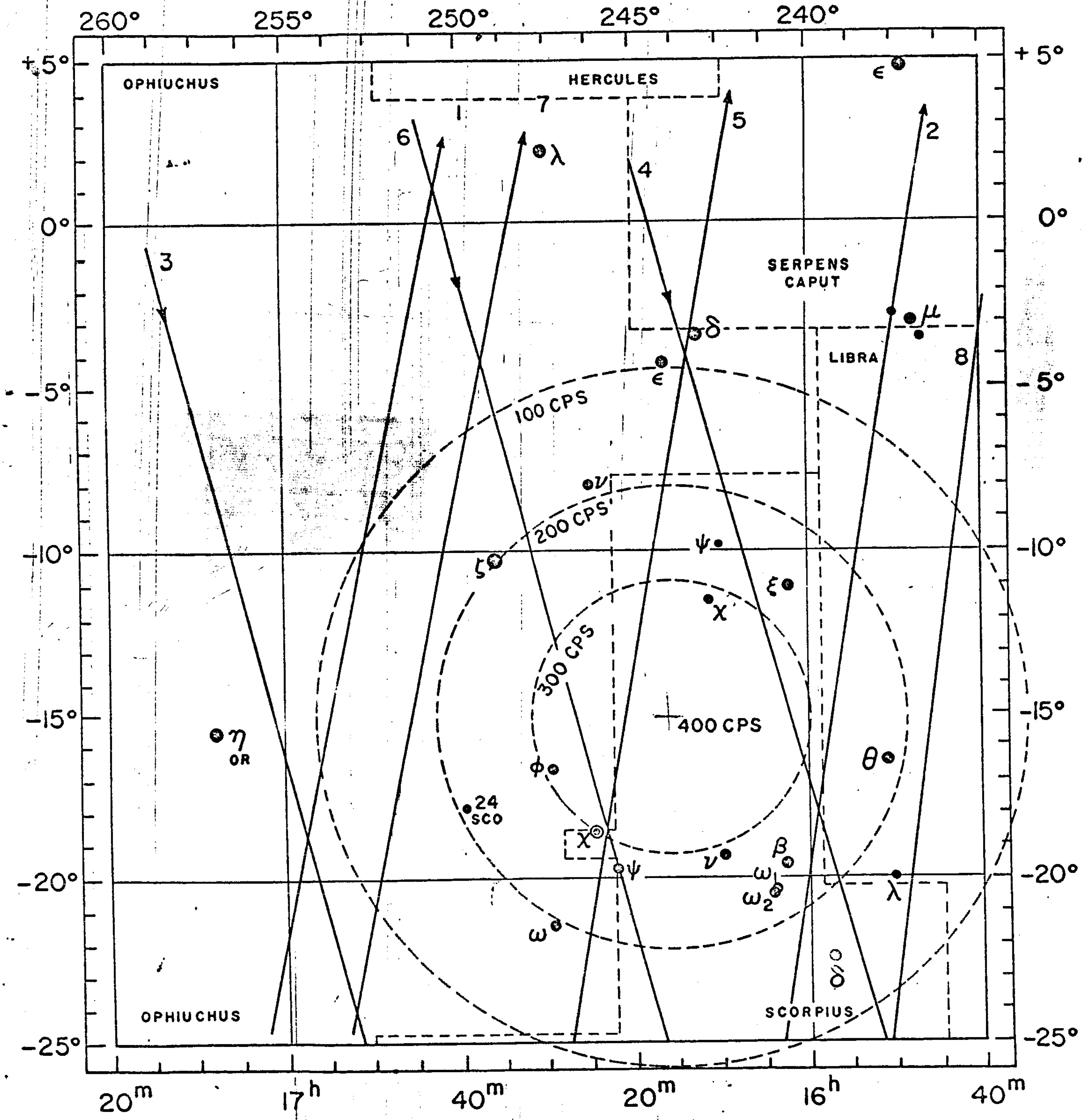


Giacconi et al
300F_h
Arnold et al
F_h
Kraushaar & Clark
10
1
10^-1
10^-2
10^-3
10^-4
10^-5
10^-3
10^-2
10^-1
1
10
10^2
Flux (MeV cm^-2 sec^-1 MeV^-1)
Photon Energy E (MeV)

FIGURE 10

Tracks of eight scans across Scorpius region: Numbers along tracks are counts per 0.09 second interval. The dashed circles are best fits to equal intensity contours and indicate a central intensity peak of 400 c.p.s. at α = 16 h 15 m, δ = - 15°.

(from Bowyer, S., E.T. Byram, T.A. Chubb, and H. Friedman, Nature, 201, 1307 (1964)


260°
255°
250°
245°
240°
+5°
0°
−5°
−10°
−15°
−20°
−25°
OPHIUCHUS
HERCULES
SERPENS
CAPUT
LIBRA
SCORPIUS
100 CPS
200 CPS
300 CPS
400 CPS
20m
17h
40m
20m
16h
40m